RESPONSES OF KENTUCKY BLUEGRASS TO VARIATIONS IN TEMPERATURE, LIGHT, CUTTING, AND FERTILIZING[1]

CARTER M. HARRISON

(WITH SEVEN FIGURES)

Of primary importance among the several environmental factors which influence the production and maintenance of turf are seasonal variations in temperature, amount and intensity of sunlight, and cutting and fertilizing practices. It has long been observed that bluegrass grows best during the cooler seasons, although the reasons for such behavior have never been fully understood.

When bluegrass is cut short and heavily watered or fertilized, especially during the hot summer months, undesirable results follow. The turf thins out, the production of new leaves ceases, and during the cooler, wetter period of fall large numbers of the plants fail to recover. In attempts to maintain a vigorous green growth, nitrogenous fertilizers are often added to such turf when actually such an addition may be harmful instead of beneficial, especially during the hot weather of summer.

With a view to determining a possible cause for the widely differing results often obtained from apparently similar practice, the following experiments were conducted in sand culture. All cultures were obtained from the vegetative propagation of one original bluegrass plant. More particularly the experiments dealt with: (a) the effect of cutting to 0.5 inch, 1 inch, and 2 inches, plants which were supplied either with a solution high in ammonium nitrogen and low in nitrate nitrogen, or one high in nitrate and low in ammonium nitrogen; (b) the type of growth produced at different seasons of the year and the effect upon such growth of varying degrees and times of defoliation; (c) the effect of cutting plants grown with a continuous nitrogen supply as contrasted with some which had had no nitrogen during a period beginning 6 weeks prior to the initial cutting and extending to the close of the experiment; (d) the type of recovery growth produced when cultures were cut back to 1 inch in height every ten days, at 60°, 80°, and 100° F., with and without a nitrogenous fertilizer. The experiments were conducted in the University of Chicago greenhouse, from the fall of 1930 to the fall of 1932.

Several recent papers contain literature reviews of some length on much the same subjects as taken up here. GRABER, NELSON, LUEKEL, and ALBERT (**2**), PIERRE and BERTRAM (**7**), LUEKEL and COLEMAN (**6**), and GRABER (**1**) have published recent papers on the food reserves of grasses in relation to

[1] Contribution from the Hull Botanical Laboratory, the University of Chicago, under a fellowship granted by the United States Golf Association, Green Section.

growth. HARRISON (3) has published a recent paper on the effect of cutting on grass development. KRAUS and KRAYBILL (5) and THOMAS (9) have fully covered the present literature on carbohydrate-nitrogen relationships.

Experimental data

EXPERIMENT I

EFFECTS OF CONTINUED CUTTING AND FERTILIZING.—An individual Kentucky bluegrass plant (*Poa pratensis*) was propagated vegetatively, split up into 4-gm. segments and planted one segment each in 2-gallon glazed pots containing white quartz sand, free of fertilizers. The plants were started April 1, 1931, and supplied with a four-salt nutrient solution, selected from the ammonium sulphate series of JONES and SHIVE (4) made up of calcium nitrate, potassium phosphate, magnesium sulphate, and ammonium sulphate in distilled water. This was supplied by the constant drip method similar to that used by ROBBINS (8), one half of the cultures receiving a solution high in nitrate and low in ammonium nitrogen ($T_3R_1C_5$) and the other half receiving a solution high in ammonium and low in nitrate nitrogen ($T_3R_5C_1$). The pH of the solution high in nitrate was approximately 4.5, while that of the solution high in ammonium was 4.8. The cultures were grown without disturbance until September 22, when five pots of each set (ammonium high and nitrate high) were taken down and the sand washed from the roots. Figure 1 gives an idea of the different types of growth of

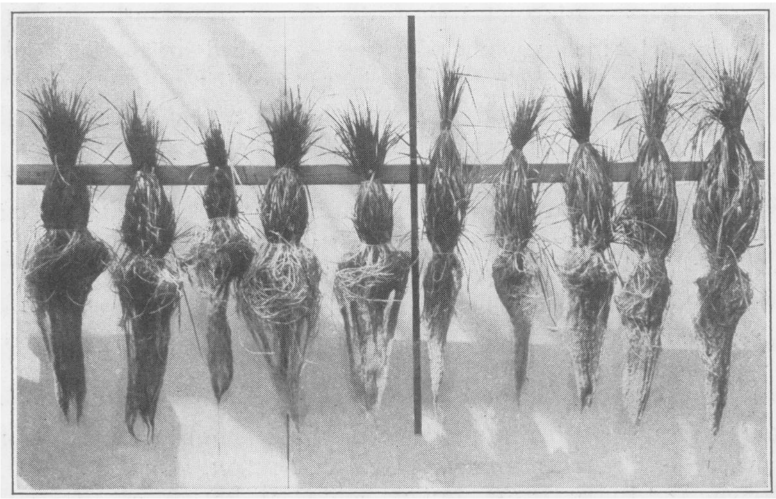

FIG. 1. Cultures on the left were grown in the solution high in nitrate and low in ammonium nitrogen, while those on the right were grown in the solution high in ammonium nitrogen and low in nitrate nitrogen. Note the habit of growth and the far greater number of rhizomes at the left.

the two sets. Table I gives the weights of the plant parts in grams after drying.

TABLE I

DRY WEIGHT OF PLANTS SUPPLIED WITH HIGH NITRATE AND HIGH AMMONIUM SOLUTION

TYPE OF SOLUTION		CULTURE NUMBER					
		1	2	3	4	5	Av.
		gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
High nitrate-low ammonium	Roots	9.5	9.1	9.5	8.5	5.2	8.3
	Tops	44.5	41.2	39.0	32.5	23.5	36.1
	Rhizomes	4.3	4.1	5.7	5.0	4.0	4.6
High ammonium-low nitrate	Roots	7.5	7.3	6.5	3.7	3.5	6.3
	Tops	42.5	38.0	30.5	19.0	16.5	29.3
	Rhizomes	2.5	2.2	1.8	0.7	1.0	1.6

The plants receiving the solution high in ammonium and low in nitrate nitrogen had leaves 15 to 22 inches long, which lay flat or drooped over the sides of the pots and were very dark green; those supplied with the solution high in nitrate and low in ammonium nitrogen had leaves 8 to 12 inches long, which were lighter green in color and stood upright in the pots. There were from 300 to 500 rhizomes in the cultures supplied with the high nitrate solution, as compared with 50 to 150 in the cultures supplied with the high ammonium solution. The former were short and thick and considerably branched as compared with the latter, which were long, thin, and unbranched.

On the same date (September 22) the leaves of five cultures of each series (high NH_4 and high NO_3) were cut to 0.5, 1, and 2 inches respectively. The clippings from this initial cutting were dried and weighed. One week later the grass was again clipped back to the same heights. It was noticed that the shorter the cutting height the shorter was the new growth made after cutting. In both sets the grass cut to 0.5 inch grew approximately 4 inches, that cut to 1 inch grew 5 inches, and that cut to 2 inches grew 6 inches. The measurements were taken above the point of the original cutting in each case. After the second cutting, during a period of high greenhouse temperatures, it was observed that the grass recovered more slowly than usual. The new leaf growth would extend upward from 1 to 3 inches and then die back from the tips of the blades. It was much more noticeable in the plants supplied with ammonium nitrogen than in those supplied with the high nitrate solution. A considerable number of the above-ground buds soon failed to produce additional new leaves or to extend those which had been cut, and upon examination they were found to be dead. Most of the plants which died soonest were in the center of the culture, which was the oldest portion. The plants started growth from the segment which was the original planting and new rhizomes extended laterally from this segment. These new rhizomes were younger than the stem from which they originated, and none of their potential leaves had extended upward. Consequently when cutting was begun, a larger proportion of the leaf area of the older portion of the plant was removed than was true in the case of the rhizomes which had just pushed above the surface of the soil or were as yet buried beneath it. The number of leaves that a given bud will produce is fixed at an early stage in its growth. The leaves in the older buds had practically all unfolded and matured, whereas in the younger rhizomes the leaves had either just begun to unfold from the bud or as yet remained underground.

The underground parts were examined to determine what was taking place under the conditions of frequent cutting, high fertilization, and high temperatures. The cultures supplied with nitrate had from 300 to 500 growing rhizome tips on September 22 before cutting was begun, and the ones supplied ammonium nitrogen had from 50 to 150. These were all below the soil line, extending vegetatively, and producing scale leaves. On examination October 15, after the two subsequent cuttings in September, it was found that every rhizome tip below the soil line, in either fertilized set and at all three cutting heights, was dead. The terminal buds of the underground rhizomes were brown and beginning to decay. The death of the tissue back from the tip depended somewhat upon the amount of green leaf tissue remaining after cutting; the more of the green tissue removed, the greater the degree of killing of the rhizome when measured back from the terminal point. The terminal bud died first and then successively the buds at the nodes back from the tip. In most cases the entire rhizome became brown and decayed. The roots on these rhizomes died and in some cultures as much as 90 per cent. of the portion above ground was killed. The younger stems toward the periphery of the culture survived. Any rhizome that had recently emerged above the soil line and was actively producing vegetative leaves also survived. As soon as these rhizomes became above-ground stems, they produced green vegetative leaves only. These new leaves were green even below the point of shortest cutting, and probably they manufactured sufficient carbohydrates to maintain the new rhizome. The older stems had a considerable number of dry leaf sheaths at their bases, however, each new leaf produced having to extend through these dead leaves before emerging into the light. Consequently at each cutting all of the green leaf tissue produced during the period since the previous cutting was removed. Figure 2 shows how the check plants and

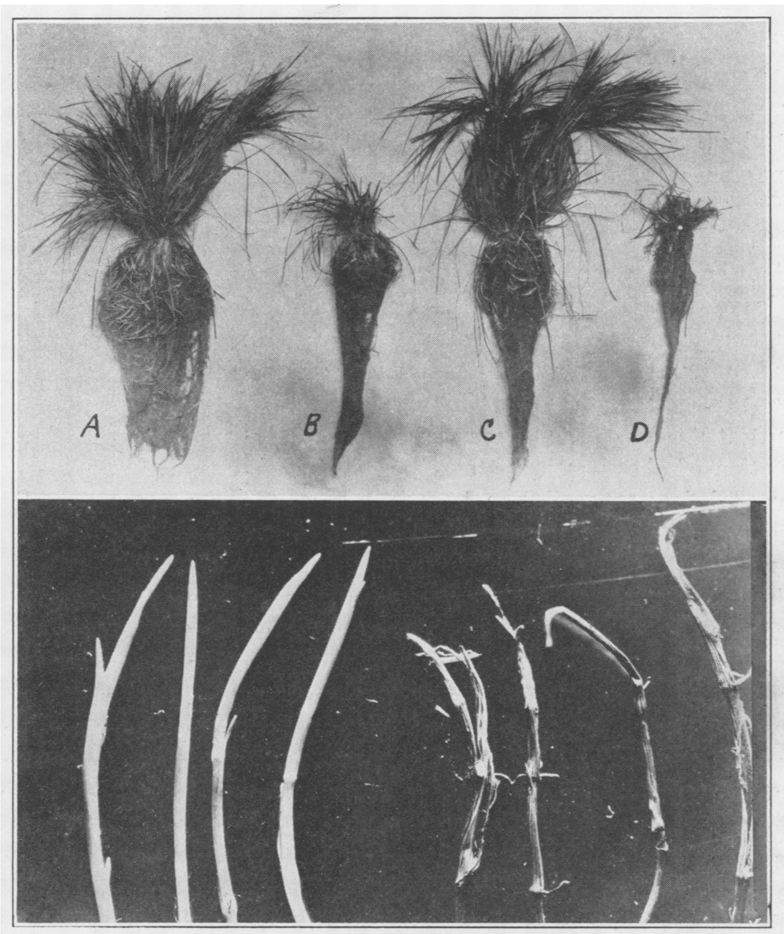

FIG. 2. Above: effects of cutting treatments on bluegrass plants. Plants *A* and *C* are uncut controls; plants *B* and *D* were cut down to 0.5 inch twice, the cuttings one week apart. The new growth apparent on *B* and *D* is that which has appeared since the last cutting 20 days previous. All the cultures were grown in sand and supplied with a nutrient solution: *A* and *B* received a solution high in nitrate and low in ammonium nitrogen, while *C* and *D* received a solution high in ammonium and low in nitrate nitrogen.

Below: at the left, rhizomes from an uncut control; at the right, rhizomes from plants cut back to 0.5 inch in height twice, the cuttings one week apart. Photographed 20 days after second cutting.

some that were cut twice appeared on October 20, approximately one month after the initial cutting. The rhizomes are enlarged about two times in figure 2. It will be noted that the rhizomes from the culture not cut are white and plump with sharp terminal points, whereas those taken from the culture that had been clipped short twice are dark and shriveled.

Experiment II

Growth of bluegrass plants at different seasons.—The bluegrass plant, when started from a vegetative segment without rhizomes, began new growth by tiller-like buds in the axils of the leaves. These buds were green on emergence and grew upright almost from the start. They produced a few green scale leaves at the base but most of the leaves were large. After this initial start, short stolons which grew 1 or 2 inches from the crown of the plant before they turned upward were produced. These produced more scale leaves than the first tiller-like buds, and roots arose near the nodes. Later short rhizomes were produced. These gave rise to scale leaves underground, but upon emergence from the sand, a short way from the crown, developed vegetative leaves. This process continued until the pot was full of upright stems. Then, when the days were long and bright, the active production of above-ground stems was somewhat retarded and there were produced below the soil line large numbers of rhizomes which did not emerge so long as the top of the plant was not cut back, or so long as the days remained long and bright.

These rhizomes produced scale leaves only, and grew in length, often around the inside of the pot and sometimes down to the bottom. In late fall and early winter, as the sunlight diminished with day length and through interspersed dark cloudy periods, few new rhizomes were produced by grass that was continually supplied with nitrogenous salts. The rhizomes which were produced below the soil level during the summer and early fall, and which produced scale leaves only, gradually turned upward at the growing point, and vegetative leaves instead of additional scale leaves were produced; the new leaves turned yellowish green and emerged above the soil line. The development and emergence of these rhizomes continued until there were no growing tips below the soil line. On plants which were heavily fertilized with nitrogenous materials, during the dark winter period, a considerable number of these rhizomes as well as roots died, probably because of a deficit of carbohydrates, either as stored substance or because of the inability of the plant to manufacture them in quantity during the short cloudy days. During this period no new roots nor rhizomes were produced to take the place of those which died.

Following the emergence of the underground rhizomes, growth was initiated in the buds in the axils of the leaves above ground, and many short tiller-like branches were produced, much the same as when the plants started growth from the original plant segment. In other words, the 300 to 500 rhizomes that were produced below the soil line during summer and early fall, when the days were long and sunny, gradually emerged as the amount and intensity of light decreased, and the production of scale leaves by these rhizomes ceased and vegetative leaves were produced. On the other hand, plants that were supplied with a minus-nitrogen nutrient solution after November 10 had produced a considerable number of new rhizomes by February 1. These increased somewhat in diameter and remained below the soil line. The tops of these plants, when the days were short and cloudy, turned yellow and grew little if any, while the root system grew deeper and more extensive. It appeared that nitrogen added at a time when the days were short and cloudy was necessary to cause emergence above the surface of the soil of rhizomes which were produced during a period of long sunny days; and that the cultures which received no nitrogen, but which were exposed to the same short cloudy days, actually continued to develop their root systems and to produce new rhizomes, with a cessation of active extension of the top. There was some death of rhizomes and roots in the cultures which were supplied continuously with nitrogenous materials. The plants supplied the minus-nitrogen solution appeared to be at a standstill both below as well as above ground, after about eight months of the treatment; and as the days became long and bright nitrogen probably became the limiting factor in growth. On the other hand, lack of sufficient light for carbohydrate synthesis in plants heavily fertilized with nitrogen probably was the limiting factor during the winter months. The difference in growth response exhibited by plants grown with and without nitrogen during the winter months is of considerable interest. The cutting factor was then introduced to see what added effect it would have on the behavior of the plants. It was found that the cutting of a plant grown under winter light conditions and supplied with nitrogen was much more disastrous than cutting one that had had no nitrogen but which had had additional light artificially added for 14 hours per day after November 10. The plants were cut back to approximately 1 inch. Table II shows how the production of top growth compared.

TABLE II

WEIGHTS OF THE CLIPPINGS PRODUCED BY TWO DIFFERENT CULTURES, ONE HAVING ADDED NITROGEN AND GREENHOUSE LIGHT ONLY, AND THE OTHER HAVING ADDED ARTIFICIAL LIGHT BUT NO ADDED NITROGEN

CULTURAL CONDITIONS	DECEMBER 15		DECEMBER 23	JANUARY 6
	INITIAL CUT GREEN WEIGHT	DRY WEIGHT	DRY WEIGHT	DRY WEIGHT
	gm.	*gm.*	*gm.*	*gm.*
– N, + added artificial light	173	46.7	2.8	1.4
+ N, greenhouse light only	176	42.0	1.3	0.3

The culture grown with nitrogen and greenhouse light only was about 90 per cent. dead at the end of the three cuttings. When cutting was begun it had only a very few slender rhizomes. Of these, first the tips and finally the whole rhizomes died. When tips were cut from these rhizomes none of the buds near the nodes back from the cut end started growth, and in most cases the entire rhizome died. A considerable number of roots also died. Ten days after the last of the three cuttings, when the plant was lifted from the pot, only 3 or 4 inches of sand adhered to the roots. At the beginning of the test, all the sand in the 10-inch pots came out as a compact mass, held together by many fine roots.

In contrast to the culture receiving added nitrogen and natural light only, that grown without nitrogen and with added artificial light was growing vigorously after the last of three cuttings. The new growth produced, after cutting off the old yellow leaves, was dark green and became more succulent with each cutting. The large number of stocky rhizomes below the soil line, present when cutting was begun, stopped producing scale leaves and grew vegetative leaves which turned upward and finally emerged above the soil line. When tips were cut from the rhizomes in this culture, buds near the nodes back from the cut end started to grow. The first bud from the cut end elongated about 0.5 inch before dying; the second, about 1 inch; but the third one elongated sufficiently to emerge above the soil line, produce vegetative leaves, and survive. At the end of the test the roots permeated the soil mass of the entire pot, making it possible to empty the pot by lifting the plant out.

As a result of giving artificial light during the winter and withholding the supply of nitrogen, the plants if left uncut turned yellow, the leaves became stiff and upright, and very few new stems were produced above ground while a considerable number were produced as rhizomes below the soil line. When given added artificial light in the winter and a continuous nitrogen supply, the plants remained succulent and green, the axillary buds elongated above ground, produced green leaves, and there was very little if any production of underground stems. As soon as the days became longer and brighter, in March and April, the plants supplied with nitrogen produced not only a greater amount of top growth than those receiving no nitrogen but also more new roots and rhizomes.

Plants that were left to grow for a period without cutting with a continuous nitrogen supply and then cut back short appeared to undergo a reduction in the amount of underground parts, namely, the roots and rhizomes. There seemed to be a balancing of the underground portion in relation to the amount of top remaining. Then, if cutting was suspended, these plants began to produce new top growth, rhizomes, and roots much sooner than a plant that was left uncut; and in two months of long, sunny

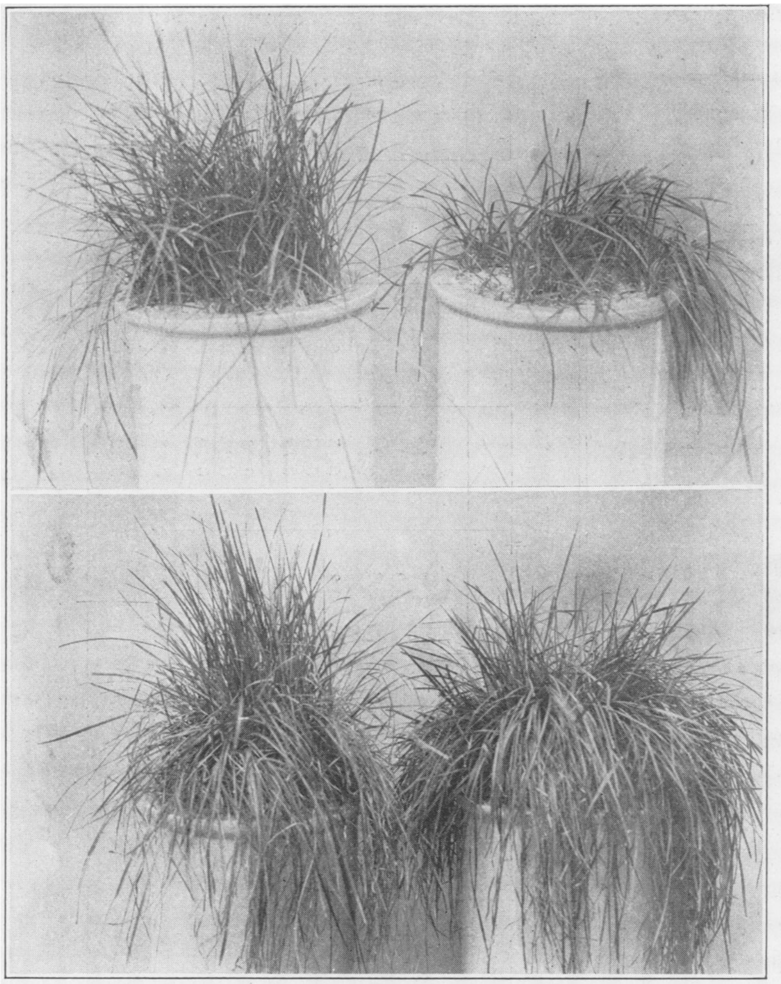

FIG. 3. Below: on the left a culture which had no nitrogen added in the nutrient solution but which had additional light after November 10 as compared with the one on the right which had a continual supply of nitrogen but no additional light. Photographed December 15; previous treatment identical.

Above: the same cultures 2 weeks after the last of three cuttings on December 15, 28, and January 6. Plants were cut back to approximately 1 inch.

days with cool temperatures the plants which had been cut and those left uncut appeared almost identical.

In order to note the amount of growth made by grass at different times of the year, cutting was continued on several of the cultures that were cut for the first time on September 22. Some were supplied with nitrogen continuously and some were given a solution containing no nitrogen. Table

TABLE III

DRY WEIGHT OF CLIPPINGS REMOVED FROM CULTURES WITH AND WITHOUT A CONTINUOUS SUPPLY OF NITROGEN AT VARYING INTERVALS OVER A PERIOD OF NINE MONTHS

CULTURE	CUT BACK TO	INITIAL CUT	SUCCESSIVE CLIPPING DATES						
		9/22/31	9/30/31	11/12/31	11/23/31	12/4/31	1/11/32	3/18/32	7/6/32
		gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
$+NO_3$	0.5 inch	29.0	1.32	5.0	0.4	0.4	0.1	3.1	42.6
	1 "	25.0	1.05	5.7	0.9	1.0	0.4	6.9	42.5
	2 "	23.0	1.05	6.7	0.8	0.9	0.2	8.1	44.7
$-NO_3$	0.5 "	29.0	1.20	3.55	0.33	0.15	0.02	Dead	....
	1 "	40.0	1.95	4.50	0.35	0.25	0.15	1.0	4.1
	2 "	34.0	1.20	6.70	0.70	0.70	0.20	0.9	3.6
$+NH_4$	0.5 "	25.0	0.50	0.10	0.02	0.03	0.02	1.1	6.5
	1 "	25.0	0.70	0.90	0.15	0.23	0.08	2.7	9.7
	2 "	29.0	1.05	1.95	0.20	0.20	0.05	2.7	6.3
$-NH_4$	0.5 "	36.0	0.60	0.50	0.07	0.15	0.05	0.6	1.6
	1 "	37.0	0.40	0.60	0.10	0.20	0.10	0.7	1.2
	2 "	27.0	0.70	1.70	0.20	0.30	0.15	1.2	1.8

III shows the weights of the clippings removed from these cultures at different times during a period of approximately nine months. The data indicate that the addition of nitrogen when the days were short and cloudy had little effect on the amount of new top growth produced.

Experiment III

Effect of cutting plants with and without an added nitrogen supply during the summer months.—The effects of cutting two cultures with different treatments, one grown with a continuous supply of nitrogen and the other supplied a nutrient solution without nitrogen, during the winter months characterized by short, cool, cloudy days, have been detailed. Tests were then made on plants during summer conditions of long sunny days with high temperatures. The plants were started on November 11, 1931, from 6-gm. segments of the same original plant used in all the previous experiments. They were supplied with a complete nutrient solution containing nitrogen in the nitrate form only. On April 21, the sand in eight cultures was washed free of nitrates and then supplied with a minus-nitrogen solution by substituting calcium chloride for calcium nitrate. The regular complete solution containing nitrate was continued on eight other cultures.

It took approximately six weeks for the accumulated nitrates in the leaves of the plants, now receiving no nitrogen, to disappear. On June 20, two months after the minus-nitrogen treatment was started, three cultures which had been receiving nitrogen and three which had received no nitrogen were dug up, the sand washed from the roots, and the plants separated into roots, rhizomes, and tops. The dry weights of the plant parts are shown in table IV. The three plants were used to serve as checks one upon the other.

TABLE IV

Dry weight of roots, tops, and rhizomes from plants grown with and without nitrogen

Cultural conditions	No.	Roots	Tops	Rhizomes	Totals
		gm.	*gm.*	*gm.*	*gm.*
Plants grown without nitrogen for two months	1	16.3	41.7	20.6	78.6
	2	16.4	38.5	21.0	75.9
	3	20.1	46.5	27.6	94.2
Plants grown with nitrogen continuously	1	13.7	59.5	15.0	88.2
	2	14.0	64.7	13.2	91.9
	3	11.8	53.2	11.7	76.7

The average dry weight of an entire plant in the minus-nitrogen set was 82.9 gm., while that in the plus-nitrogen set was 85.6 gm. The difference in dry weight between the whole plants in the two treatments was very small, but the relative amounts of the different parts of the plants, roots, tops, and rhizomes, showed considerable variation. The usual preponderance of tops to roots in the cultures supplied continuously with nitrogen is shown.

On June 21, the remaining five of each set were cut back to 0.75 inch above the level of the sand in the pot. The cutting was continued once each week thereafter, the clippings collected, and the green and dry weights recorded. Table V shows the weights of clippings removed.

TABLE V

GREEN AND DRY WEIGHTS OF CLIPPINGS REMOVED FROM CULTURES WITH AND

Conditions	No.	June 21		June 30		July 7		July 14		July 21		Jul
		G. wt.	D. wt.	G. wt.	D. wt.	G. wt.	D. wt.	G. wt.	D. wt.	G. wt.	D. wt.	G. wt.
		gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.
Cultures receiving continuous nitrogen supply	1	240	62.8	12.4	1.6	7.8	1.2	2.5	0.6	1.1	0.3	0.5
	2	192	49.2	10.1	1.5	5.8	0.9	2.6	0.6	2.8	0.8	1.3
	3	245	65.5	10.0	1.5	6.6	1.0	3.0	0.8	2.8	0.8	1.0
	4	235	61.4	10.6	1.6	8.6	1.4	2.8	0.7	1.9	0.6	1.4
	5	242	63.5	7.5	0.9	5.3	0.9	2.7	0.7	1.2	0.4	0.7
Cultures grown without nitrogen since April 21	1	121	38.2	5.1	0.7	3.2	0.6	2.9	0.9	1.5	0.5	0.9
	2	165	48.1	6.1	0.9	3.7	0.7	2.5	0.8	2.2	0.7	1.4
	3	153	47.7	5.1	0.7	3.5	0.6	1.6	0.5	2.4	0.7	1.4
	4	151	42.9	4.6	0.6	3.8	0.7	1.4	0.4	1.9	0.6	1.1
	5	173	53.9	5.5	0.8	4.5	0.8	1.8	0.5	3.9	1.1	2.0

It will be noted from table V that the cultures which received a continuous nitrogen supply produced considerably more tops, removed in the initial cutting, than those supplied with a minus-nitrogen solution. Also the clippings removed from these cultures each week, for the first three weeks after the initial cut, were greater in weight than the clippings from those receiving no nitrogen. On the average, however, those removed at the fourth cutting were greater in weight from the cultures receiving no nitrogen than from those which had had a continuous supply. For the following nine weeks this same balance in favor of the cultures receiving no nitrogen held true. The cultures supplied with nitrogen exhibited a very weak growth which was pale green in color. Those which had been growing without nitrogen started very slowly the first week after the initial cutting. They grew about 1.5 inches while the cultures supplied continuously with nitrogen grew 4 inches. The cultures without nitrogen changed in color from a yellowish green at the start of the test to a dark green which was maintained until the close of the experiment. A considerable number of new stems appeared above ground in these cultures, while in those supplied nitrogen no new stem tips were visible.

A study of the underground parts of the cultures on June 30 showed no difference between the two sets of cultures; but on July 7, approximately two weeks after the initial cutting, a large number of the rhizome tips in the cultures supplied continuously with nitrogen were dead. In the cultures supplied with the solution containing no nitrogen there were no dead rhizome tips observable, but the growing points of the rhizomes were turning upward, and a few were producing, in place of scale leaves, yellowish vegetative leaves which were emerging above the soil line. At no time did any new rhizomes or stem tips appear above ground in the cultures supplied continuously with nitrogen. On July 20, after four weekly cuttings (that is, one month after the initial cuttings), all of the rhizome tips and a considerable number of the whole rhizomes in the cultures supplied with nitrogen were dead. No dead rhizomes were found in the cultures that had had no nitrogen since April 21. A large number of the rhizomes in these cultures had emerged above the soil line and were actively producing vegetative leaves. Some of them branched somewhat underground, but on August 15 practically all that were below ground at the start of the test had emerged above the soil line. No dead stems were noticeable in these cultures. At the same date, in the cultures which were supplied with nitrogen continuously, practically all of the rhizomes had died before emergence; likewise the roots attached to them and about 60 per cent. of the above-ground stems present at the beginning of the test had died.

TABLE V

CONTINUOUS NITROGEN SUPPLY DURING THE SPRING AND SUMMER MONTHS

UST 4	AUGUST 14		AUGUST 21		AUGUST 28		SEPTEMBER 4		SEPTEMBER 12		SEPTEMBER 20		SEPTEMBER 27	
D. WT.	G. WT.	D. WT.	G. WT.	D. WT.	G. WT.	D. WT.	G. WT.	D. WT.	G. WT.	D. WT.	G. WT.	D. WT.	G. WT.	D. WT.
gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
0.1	0.3	0.1	0.2	0.5	0.2	0.05	Dead							
0.5	2.1	0.6	1.6	0.4	1.7	0.4	0.8	0.2	1.1	0.2	1.1	0.3	0.8	0.2
0.3	1.2	0.3	1.0	0.2	1.0	0.2	0.7	0.2	1.2	0.2	1.2	0.3	1.2	0.3
0.3	1.1	0.3	0.8	0.15	0.7	0.15	0.2	0.05	0.7	0.15	0.2	0.05	0.2	0.05
0.1	0.3	0.1	0.3	0.05	0.2	0.05	0.1	Dead						
0.5	2.1	0.7	1.7	0.5	1.7	0.4	1.1	0.4	2.4	0.5	2.2	0.6	1.4	0.5
0.5	2.7	0.8	1.9	0.6	1.8	0.4	1.2	0.4	2.2	0.5	2.2	0.6	1.2	0.4
0.5	2.7	0.8	1.9	0.6	1.6	0.4	1.1	0.4	2.2	0.5	2.1	0.6	1.5	0.5
0.4	2.2	0.6	1.6	0.4	1.4	0.35	0.9	0.2	1.3	0.3	1.2	0.3	0.8	0.2
0.5	2.6	0.7	1.8	0.5	1.6	0.4	1.2	0.3	2.5	0.5	2.5	0.7	1.5	0.5

The yield of top growth was also influenced by temperature. During the week from July 21 to 28, characterized by bright days and high temperatures, the yield decreased considerably in both sets of cultures when compared with the previous week or the following one. The day temperatures during most of the week reached a maximum of 120° F. and the night temperatures rarely went as low as 80° F. The following week (July 28 to August 4) the day temperatures reached a maximum of 90° F. and the night temperatures frequently went as low as 65° F. The week from August 27 to September 4 was also a very hot week and the yields were approximately half of what they were for the following week, which was cool.

On September 27 the experiment was discontinued. Two of the five cultures which had had a continuous supply of nitrogen were completely dead and a third was practically so. Of the two remaining, approximately 50 per cent. of the original top growth was dead. The individual plants still remaining alive were very shallow-rooted. All the rhizomes in all five cultures, together with the roots attached to them, were dead. On the other hand, the cultures which had been grown since April 21 without nitrogen had many small roots still present and alive. These cultures were beginning to show a nitrogen deficit, as evidenced by yellowing of the leaves. A considerable number of rhizome tips were still present below the soil line and no dead tips were discernible.

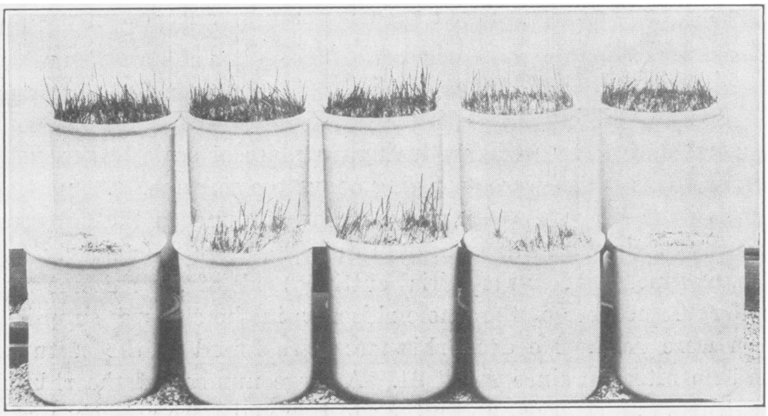

FIG. 4. Top row shows the five cultures which had no external nitrogen supply after April 21; bottom row shows the five cultures which had a continuous nitrogen supply. It will be noted that the two end cultures on the bottom row are completely dead.

EXPERIMENT IV

EFFECT OF CUTTING AND FERTILIZING ON GRASS GROWTH AT DIFFERENT TEMPERATURES.—It has long been recognized that Kentucky bluegrass makes a better growth in cool weather than in hot. What effect would cutting at different temperatures have on the recovery growth of the grass? Will it grow faster at high temperatures than at low? How will rhizomes react to the different temperatures?

In order to answer these questions, some cultures which had been started on January 7 from 6-gm. segments were placed, on July 15, in constant temperature glass cases. All these cultures had received a complete nutrient solution, containing nitrogen in the nitrate form only, until May 30, after which they were supplied with a minus-nitrogen solution. The constant temperature cases were set at 60°, 80°, and 100° F. respectively. The temperatures in all of the cases varied slightly but never more than 3°. The humidity of the air was adjusted so that the saturation deficit would be approximately the same at all three temperatures. Eight cultures were placed in each case: four were supplied with a complete nutrient solution containing nitrogen in the nitrate form only, and four were supplied with a minus-nitrogen solution. The plants were left at these temperatures without cutting for five days. All of the cultures at 100° F. were beginning to turn more yellowish at the end of this period, whereas those at 80° and 60° which had been supplied with nitrogen were turning a dark green. No color change could be noted in the cultures receiving a minus-nitrogen treatment at these temperatures.

On July 20 the grass was cut back to approximately 1 inch and the weights of tops removed recorded. On July 24, nine days after the beginning of the test, it was observed that the rhizomes were dying rapidly in the cultures at 100° F. They appeared to be dying faster in the cultures supplied with nitrogen than in those not receiving nitrogen. No rhizomes had died in any of the other four sets of cultures. The cultures subjected to 100° F. grew very little either with or without nitrogen. The grass was again clipped back to the 1-inch height, ten days after the initial cutting

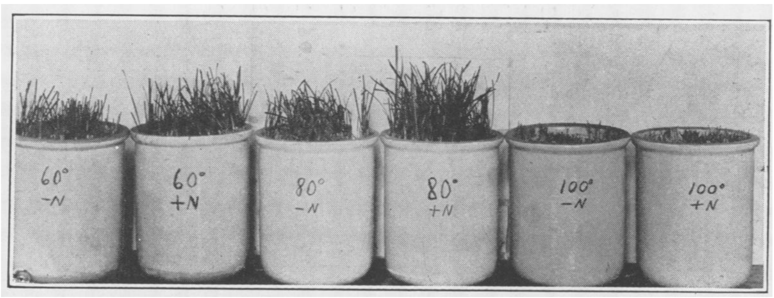

FIG. 5. Photograph taken July 27, showing the first week's recovery growth after the initial cutting on July 20 of cultures grown at three different temperatures, with and without nitrogen.

TABLE VI

AVERAGE GREEN AND DRY WEIGHT OF FOUR CULTURES AT 100°, 80°, AND 60° F. WITH AND WITHOUT NITROGEN

DATE	100° F. − N		100° F. + N		80° F. − N		80° F. + N		60° F. − N		60° F. + N	
	G. WT.	D. WT.	G. WT.	D. WT.	G. WT.	D. WT.	G. WT.	D. WT.	G. WT.	D. WT.	G. WT.	D. WT.
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
(Initial cutting) July 20	106.6	37.9	98.5	35.9	129.0	44.8	106.4	37.5	128.2	44.2	114.1	39.7
July 30	1.05	0.29	0.9	0.25	6.5	1.5	12.8	2.5	5.4	1.1	10.6	1.8
August 9	No growth				4.0	0.9	6.4	1.2	2.4	0.47	10.4	1.8
August 20	No growth				3.0	0.8	3.7	0.8	1.6	0.4	9.8	1.8
August 31	No growth				2.8	0.6	3.2	0.5	1.6	0.3	10.5	1.9
September 12	No growth				3.5*	0.8	3.7	0.7	1.9	0.4	10.9	1.7

* Average of three cultures. Some solution containing nitrogen was accidentally spilled into one of the four cultures so it was discarded.

and every ten days thereafter until the close of the experiment. The weights of the tops removed from each culture are recorded in table VI.

The cultures at 100° F. were discontinued August 31 as none of them were growing and all of the original tops appeared dead with the exception of two or three leaves in the minus-nitrogen set. The pots were left in the greenhouse and watered daily. The temperature reached a minimum of around 70° F. during the night, which was considerably cooler than the temperature to which they had been previously exposed. On September 12 it was noted that a few spindling light green leaves were appearing around the edges of all the cultures except one of the four which had been supplied with nitrogen. Upon closer examination it was observed that this growth was coming from some of the dormant lateral buds on a very few of the rhizomes, in no instance from the terminal bud.

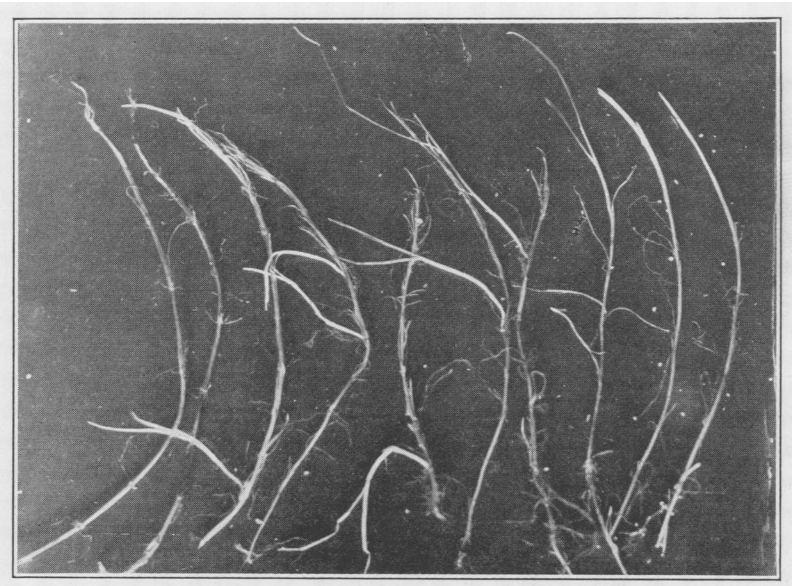

FIG. 6. On the left two rhizomes which were completely dead. The next five show the nature of the recovery growth from the rhizomes in the 100° F. cultures. Note the new growth back from the tip of the rhizome and the dead portion above it. Next to these five is shown a rhizome which had just emerged above the soil line and was producing vegetative leaves. The last two on the right show the appearance of the rhizomes underground and producing only scale leaves.

At the end of the test the cultures were separated into living tops, dead tops, roots, and rhizomes. No attempt was made to separate the dead underground tissue from the living portions. Table VII shows the weights of the different portions at the close of the test.

FIG. 7. Photograph taken September 20 showing nature of the top growth produced during the last week of the test. Note the thickening up of the grass in the cultures at 60° + N and the spindling growth in the cultures exposed to 100° until August 31.

TABLE VII

DRY WEIGHT OF PLANT PARTS AT END OF TEST (AVERAGE OF FOUR CULTURES)

PARTS	100° – N	100° + N	80° – N	80° + N	60° – N	60° + N
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Roots	10.5	9.9	12.2	9.3	16.4	11.2
Rhizomes	6.1	7.0	7.4	7.7	12.9	9.2
Living tops	0.25	0.16	7.7	2.8	8.4	12.3
Dead tops	4.5	4.5	1.6	4.9	None	None

Table VII shows that the roots and rhizomes in the cultures at 60° without nitrogen weighed far more at the conclusion of the test than those of any of the other cultures; also, that there were no dead tops whereas there were many at the other two temperatures. Obviously either high temperatures or the addition of nitrogen may bring about a decrease in the weight of the underground storage portions of the plant.

It will be observed from figure 5 and table VI that the grass made very little recovery growth either with or without nitrogen at 100° F. After the second cutting these cultures did not produce any new top growth until after the exposure to 100° F. was discontinued. The tips of the rhizomes were practically all dead in both sets and very little green top growth was noticeable. At 80°, the production of new leaves after cutting was very rapid when nitrogen was added and much slower in the minus-nitrogen treatment. The leaf blades in the cultures without nitrogen were short and broad, while those receiving nitrogen were long and narrow. None of the rhizomes present at the beginning of the test had begun to appear in either set. On closer examination, it was observed that the tips of a number of rhizomes were dying underground in the cultures receiving nitrogen, whereas those supplied with a minus-nitrogen treatment were turning upward and growing toward the surface of the sand. The weight of the clippings removed after the first ten days from the cultures receiving a minus-nitrogen treatment was approximately one-half of that removed from the cultures receiving nitrogen. One month later the clippings removed were approximately the same in both sets, with or without nitrogen. At 60°, in the cultures supplied with nitrogen, the first observable change was the emergence of a large number of rhizome tips, which were underground at the beginning of the test. These had grown rapidly upward through the sand and emerged into the light. Tiller-like buds at the base of the leaves of the older above-ground stems were also beginning to grow and produce vegetative leaves. The top growth of these cultures, which consisted primarily of upright leaf blades, became considerably denser, and although the grass did not grow so tall as it did at 80° with nitrogen, the weight of the recovery growth was almost equal. One month after the initial cutting, the figures show that the cultures supplied nitrogen at 60° were producing approximately three times as much weight of tops as the cultures receiving nitrogen at 80°. This difference was largely due to the increased number of new, above-ground stems in the cultures at 60° which were producing leaves. At 60°, when the cultures were supplied with nitrogen the rhizomes grew upward into the light, while at 80° they died before emerging and no new tiller-like buds were produced by the older above-ground stems. Much more green leaf tissue was left after cutting in the case of the grass in the cultures at 60° supplied with nitrogen than at 80°, because these new stems were green on emergence and had considerable leaf area left below the cutting point; whereas most of the green tissue was removed from the cultures at 80°. The cultures at 60° without nitrogen very slowly produced new top growth following cutting, and upon closer examination it was noted that these plants were actively producing new roots, a characteristic not observable in any of the other sets of cultures. Even after the fourth successive cutting these cultures were still producing new roots.

Summing up the general observations on the effects of the variations in temperature, the following points can be noted: (1) at 60°, minus nitrogen, the top growth recovery following cutting was slow, none of the rhizomes pushed out above the soil, and the cultures produced many new roots; (2) at 60°, plus nitrogen, no new roots were produced but many of the rhizomes below ground at the beginning of the test turned upward and pushed above the soil line; (3) at 80°, minus nitrogen, no new roots were produced and some of the rhizomes gradually appeared above ground; (4) at 80°, plus nitrogen, no new roots were produced, no rhizomes appeared above ground, and a large number of rhizomes and roots died; (5) as the number of cuttings increased, the yield of tops between cutting periods in the cultures receiving the treatment of minus-nitrogen at 80° was beginning to approximate the yield of those receiving nitrogen; (6) at 100°, in either set there was very little new top growth and the rhizome tips and the roots practically all died.

A final consideration of the results of the various experiments, as set forth in the foregoing tables and illustrations, brings out several characteristic responses of Kentucky bluegrass to changes in temperature, amount and intensity of light, variations in nitrogen supply, and cutting practices.

Tables II and III and figure 3 show that bluegrass did not grow the same in winter when the days were short and cloudy as it did in summer when the days were long and sunny. The plants produced the largest amount of new tops, roots, and rhizomes during the spring and fall when the temperatures were not excessively hot or cold, and the days were bright and long. The plants, during the long, sunny days of spring, summer, and fall, produced a large number of rhizomes if continuously fertilized with nitrogen and left uncut; but as the short cloudy days of winter arrived, these rhizomes turned upward and emerged into the light above the soil line. If the nitrogen supply was discontinued during this period of short, cloudy days, the rhizomes not only remained below the level of the ground but became stockier and increased in number. Severe cutting of the tops of a culture continuously supplied with nitrogen was much more disastrous during this short cloudy period than during the period of long, bright days of spring, early summer, and early fall. If the days were long and sunny but characterized by excessively high temperatures, the cultures produced less new growth between cuttings than they did when the temperatures were lower.

On the other hand, close and frequent cutting of a plant that had been growing for some time without an external supply of nitrogen and the leaves of which had turned from green to yellow did not bring about the death of any of the above-ground stems, roots, or rhizomes. This plant had a large number of thick, tough rhizomes; the plants continuously supplied with nitrogen and grown during the period of long sunny days had fewer and more succulent rhizomes; whereas the cultures grown with a continuous supply of nitrogen during the winter had none. The rhizomes of the latter had either come up to the surface or died before emergence. It seems evident that the rhizomes may store a supply of carbohydrates which may be used by the plant during periods of short and frequent clipping or during periods of dark, cloudy weather. When the plants were kept extremely vegetative very few rhizomes were formed, and when in this condition, close and frequent defoliation resulted not only in lessened production of new leaves but actually caused death of the stems above ground, and of roots and rhizomes.

The plants which were grown in the winter period of dull, cloudy days, and which received a continuous supply of nitrogen, had practically no rhizomes and therefore had very little underground storage supply of carbohydrates. If the tops of these cultures were kept cut off continuously the plants died very soon, while others without nitrogen and which had a large number of thick, sturdy rhizomes continued to produce new top growth; and none of the roots, rhizomes, or above-ground stems died during the course of the experiment. As the cutting continued, the rhizomes of the plant without nitrogen gradually turned upward, and emerged above the soil line and produced mainly vegetative leaves. The amount of defoliation that a grass plant will survive is largely dependent upon the rate at which the carbohydrates, stored in the underground portions of the plant, are used up. When the plant is completely defoliated, the drain upon the reserve carbohydrates is much more severe than it is when considerable leaf area remains after cutting. When temperatures are between 70° and 90° F., and there are sufficient moisture and nutrients, the new leaves produced grow quickly and rapidly. The constant removal of this new growth soon brings about the death of these plants through carbohydrate starvation, whereas with constant cutting a plant with high carbohydrate storage and without an external supply of nitrogen grows slowly during the periods between cuttings, thus utilizing smaller amounts of the stored carbohydrates and continuing growth over a longer period of time. In the case of the vegetative plant, a large amount of top growth is removed at each cutting; but such cutting can continue only over a short period of time, after which the development of new leaves becomes slower and slower until the plant in many cases actually dies. In contrast to the vegetative plant, a small amount of top growth is removed from the non-vegetative plant at each cutting, but the production of new leaves continues over a much longer period of time.

These results as a whole indicate that fertilization of grass with nitrogenous fertilizers during periods of short and frequent cutting at high temperatures does not result in an increase of growth but may even result in a decrease. Several factors, such as short and frequent clipping, shade, short cloudy days, nitrogen fertilizers, heavy watering, and high temperatures tend toward the using up of such supply of stored carbohydrates as may be available, and if carried to such an extreme that these carbohydrates are completely utilized and are not made available through the activity of additional leaf area, ultimate death of the plant may be brought about. Short and frequent cutting and fertilizing with nitrogen may help considerably in the production of a denser turf provided the plants have a carbohydrate reserve, or a ready means of its manufacture, and the weather remains cool and bright.

Summary

1. The leaf blades of bluegrass cultures supplied with calcium nitrate were shorter and more upright, the rhizomes were more numerous, stockier, and more branched than was the case when the plants were supplied with ammonium sulphate.

2. The rhizomes and a large proportion of the roots of vegetative cultures were killed by short and frequent defoliations.

3. The plants exhibited a different type of growth at different seasons of the year, when light conditions, nitrogen supply, and cutting practices were varied. Rhizomes produced in cultures left uncut during the bright cool days of spring, early summer, and early fall and continuously supplied with nitrogen, gradually emerged into the light as the short cloudy days of late fall and winter arrived. By limiting the nitrogen or increasing the light, these rhizomes not only remained below the soil level but became stockier and new ones were also produced.

4. It was possible to influence the amounts and relative proportions of various plant parts by limiting the nitrogen supply. As the nitrogen supply was decreased, the relative amount of top growth diminished as the roots and rhizomes increased.

5. Cutting back the leaves of non-vegetative plants supplied with a minus-nitrogen nutrient solution, and which had a large quantity of storage rhizomes, was less harmful during the hot summer months than was short cutting of vegetative plants which received a continuous supply of nitrogen and which had a much smaller quantity of storage rhizomes. It was possible to kill plants that were continuously fertilized with nitrogen by frequent defoliations.

6. Plants grew very little at 100° F., after defoliating, with or without nitrogen; and a large part of the established cultures died during six weeks of such exposure. A few dormant buds on the rhizomes recovered after the exposure was discontinued and the temperature lowered. In no case was such recovery from a terminal bud on the rhizome but rather from a bud several nodes back from the tip.

7. When cultures exposed to 80° F. and supplied with nitrogen were periodically defoliated, new leaves were produced which grew rapidly. This rapid growth exhausted the reserve supply of carbohydrates during the first few periods; and as the defoliations were sufficiently frequent to prevent a replenishing of the supply, the growth made between cuttings became less and less. Finally these cultures were producing no more new

growth between the periods of defoliation than were cultures exposed to the same temperature but supplied with a minus-nitrogen solution. The tips of the rhizomes in the cultures supplied with nitrogen died, while the rhizomes in those receiving no nitrogen turned slowly upward and emerged above the soil line.

8. At 60° F., when the cultures were supplied with nitrogen the new leaves produced after a defoliation grew much more slowly than was the case at 80° F., but soon practically all of the rhizomes present at the beginning of the test had emerged above the soil line, and tillered profusely on emergence; and these cultures, because of this different habit of growth, were soon producing a much higher yield of new growth between defoliations than were the cultures at 80° F.

9. At 60° F., without nitrogen, the response to close cutting was the production of many new roots. During the course of the experiment the rhizomes remained below ground and no dead tips were discernible. The cultures yielded very little new top growth during the periods between defoliations.

DEPARTMENT OF BOTANY
UNIVERSITY OF CHICAGO

LITERATURE CITED

1. GRABER, L. F. Food reserves in relation to other factors limiting the growth of grass. Plant Physiol. **6**: 43–72. 1931.
2. ———, NELSON, N. T., LUEKEL, W. A., and ALBERT, W. B. Organic food reserves in relation to the growth of alfalfa and other perennial herbaceous plants. Wisconsin Agr. Exp. Sta. Bull. 80. 1927.
3. HARRISON, C. M. Effect of cutting and fertilizer applications on grass development. Plant Physiol. **6**: 669–684. 1931.
4. JONES, L. H., and SHIVE, J. W. The influence of ammonium sulphate upon plants supplied with ferric phosphate and ferrous sulphate as sources of iron. Jour. Agr. Res. **21**: 701–728. 1921.
5. KRAUS, E. J., and KRAYBILL, H. R. Vegetation and reproduction with special reference to the tomato. Oregon Agr. Exp. Sta. Bull. 149. 1918.
6. LEUKEL, W. A., and COLEMAN, J. M. Growth behavior and maintenance of organic foods in Bahia grass. Florida Agr. Exp. Sta. Bull. 219. 1930.
7. PIERRE, W. H., and BERTRAM, F. E. Kudzu production with special reference to influence of frequency of cutting on yield and forma-

tion of root reserves. Jour. Amer. Soc. Agron. **21**: 1079–1101. 1929.

8. Robbins, W. R. Nutrient requirements of the sweet potato plant when grown in sand culture, and effect of various nutrient salt proportions on the composition of the roots. New Jersey Exp. Sta. Ann. Rpt. pp. 178–179. 1927.
9. Thomas, Walter. Composition of current and previous season's branch growth in relation to vegetative and reproductive responses in *Pyrus malus* L. Plant Physiol. **7**: 391–445. 1932.